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THE CONTROL OF DOTHIORELLA ROT ON AVOCADO FRUITS

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THE CONTROL OF DOTHIORELLA ROT ON AVOCADO FRUITS[1, 2]

W. T. HORNE[3] AND D. F. PALMER[4]

A DECAY OF AVOCADO FRUIT caused by the fungus dothiorella[5] was early observed by H. S. Fawcett and others, but its importance became evident only with the growth of the California avocado industry. It is not the most widespread, nor is it the most rapidly destructive or most offensive form of spoilage. However, certain features, as pointed out further on, have made it peculiarly troublesome. It has at times occasioned serious economic losses in the affected districts, both by losses of fruit and through discrimination against fruit from certain districts regardless of whether it was affected or not. Early efforts at control based on experience with citrus fruits were not successful.

CAUSE

Dothiorella is a comparatively common fungus of wide distribution. It was studied by H. S. Fawcett in connection with a large canker on trunks and limbs of English walnut in California, and the disease which it produces was called melaxuma (black sap). In this case, cankers in the wild willows growing nearby were found to be an important source of infection. The fungus is also frequently found in dead twigs of the walnut. In New York it was studied as the cause of a serious disease of cultivated red currants, which produced cane blight.

It is sometimes important in moist seasons or situations, causing a stem-end rot of citrus fruits, with two other fungi which produce similar effects, *Diplodia natalensis* Evans, and *Phomopsis citri* Fawcett. In the avocado the dothiorella fungus is found on decaying fruits, in the dead areas of tipburned leaves, and in the bark of dead twigs.

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[5] *Botryosphaeria ribis chromogena* Grossenbacher and Duggar, which before the discovery of the perfect stage was called *Dothiorella gregaria* Sacc., and which has been referred to, probably incorrectly, as *D. ribis*.

LOCAL NATURE OF THE TROUBLE

Dothiorella rot is only one of a number of decays which attack the avocado, and except in certain places where it is severe, it is of no greater importance than various other types of rot. It probably occurs throughout California wherever avocados are grown, but merchants have experienced serious losses only from fruit grown in certain coastal areas. A

Fig. 1.—Lower end of a Fuerte avocado showing the light dots or flecks and speckles. This fruit does not have dothiorella rot or other aggressive form of decay.

moist climate and tipburn of the leaves appear to be highly important predisposing conditions.

TIME OF DEVELOPMENT OF ROT

Dothiorella rot does not usually develop on sound fruits hanging on the tree or on the fruit after it is picked until softening begins. In typical cases with Fuerte fruits at the stage known as "breaking" (the first detectable softening), small dark spots with vague boundaries appear. Not all the dothiorella spots develop at the breaking stage, but new areas continue to make their appearance as softening progresses. The fact that the firm fruit shows no sign of the trouble and that no method is available to distinguish those fruits which are to develop the decay from those which are not destined to develop it, gives opportunity for serious trouble between grower and merchant.

THE CHARACTER OF DOTHIORELLA ROT

Dothiorella rot spots may be seen when less than ⅛ inch in diameter. At this stage they are light umber, rather vaguely bounded, and not

sunken nor distinctly marked. They often spread out from a speckle or other blemish as a somewhat paler margin. Figure 1 shows speckles, none of which are developing dothiorella spots, while figure 2 shows dothiorella spots, some of which are spreading out from speckles. As the spot becomes more distinct, it darkens slightly but is not black in the early stages.[6] Speckles might be confused with dothiorella rot; they are

Fig. 2.—A Dorothea fruit with typical dothiorella rot; notice eye-rot at the stem attachment.

dark and sunken and rarely more than $\frac{1}{16}$ inch in diameter, and, unless some complication appears, involve only the skin of the fruit. The dothiorella spot, by contrast, may become $\frac{1}{2}$ inch in diameter within 3 or 4 days. The latter is circular, not sunken, and is rather uniformly colored. If the surface is scratched, it is found to be softer and more easily broken than the sound surface. If cut, most of the rot will be found to be in the skin, and if the flesh is at all affected, only the outermost part shows a slightly watery condition.

From this stage the spot spreads more rapidly, becomes soft and somewhat sunken and uneven, while a watery rot spreads rather slowly into the flesh. A rank odor develops. Sometimes the rotting fruit fades out to a greenish gray. The surface settles and becomes uneven. Later, the whole fruit shrivels up and becomes dark. If a bit of the decaying flesh is put in a drop of water, it is easily crushed, and under the com-

[6] Color of the rather well-established spots on Fuerte fruits by Ridgway's color chart is approximately mummy-brown to bone-brown. The later, softer phase may be raw umber to light brownish olive or lighter.

pound microscope shows strong branching fungus threads of varying breadth. The seed is not ordinarily affected.

At a wound or at the stem attachment, dothiorella rot may appear earlier than on other parts of the fruit and penetrate more deeply and rapidly. When it attacks the stem attachment, it produces a form of eye-rot[7] (fig. 2). While the rot shown in figure 2 is mainly superficial, some odor will have penetrated the flesh, and utilization after this stage will be disappointing.

SOURCES OF INFECTION

When the decayed fruits become old and dark, the surface develops numerous small pimples at the tops of which minute spore masses may appear as drops or coils. These spore masses emerge from fungus pockets (pycnidia), and similar structures are formed in the dead areas of tip-burned leaves and in the bark of dead twigs. If the surface of an affected twig is lightly shaved so as to cut off the tops of the prominences, white dots may be seen, each dot surrounded by a black ring. In rainy or wet times, spores emerge from these pycnidia and are freely washed and spattered about. Spores of another sort are also formed which may be shot to a distance of about ½ inch. While these spores are comparatively large and heavy, they still may be carried considerable distances in a driving rainstorm. It is believed that the spores are mainly of rather local distribution, and that they drift very little in dry air, in this way being unlike the excessively light and dusty spores of citrus blue mold.

Spores on fallen leaves and twigs probably do not readily get up into the tree so that in our opinion it is unnecessary to remove the mulch. An additional light cover of straw or other material should make it entirely safe. Dead twigs should be removed periodically, which can best be done at the time of the principal leaf drop in the spring and again in the autumn.

METHOD OF PENETRATION BY THE FUNGUS

Once a spore is deposited on the moist fruit, it germinates by sending out a tube-like thread; this grows down through one of the openings in the skin by which the fruit is supplied with air, and into one of the air spaces below. These air spaces are marked by the yellow flecks of the avocado skin, and in them the fungus makes considerable growth, but is unable to attack and destroy the living skin until the time of softening of the fruit.

Preparations for microscopic study[8] clearly show the fungus in the

[7] Eye-rot is any rot which spreads from the point of attachment of the fruit stem; it may be caused by various organisms, but most of these are less capable of becoming established on the sound skin than is dothiorella.

[8] Preparations used were made by Dr. Ira Ayer, of Carlsbad, California.

open spaces below the surface of the skin of sound avocado fruits (fig. 3). Protection of the fungus in these spaces will explain the difficulty of preventing the rot by treating the surface of harvested fruit with fungicides.

THE FUERTE AVOCADO AND DOTHIORELLA ROT

Fuertes in the coastal area bloom through a long period; in fact, some flowers can be found at almost any time. The principal time for blossoming and setting fruit is from March to May, but many fruits are set at other times; these are "off-blooms." They tend to be small and ill-shaped and do not mature with the principal crop. The most skillful growers can now judge fairly well the state of maturity of a Fuerte fruit, if it can be seen in a good light, but selective picking is troublesome and difficult. Many off-blooms in the past have become excessively senile, so that they failed to soften normally when picked. In these cases, dothiorella rot often developed early, and the whole surface was rotted before the inner flesh was fully soft. The foregoing statement is based on general observations, but careful study of the softening process and its failure with senility of fruit is lacking. There is a growing opinion that it would be better to cut down and destroy the off-blooms at about the time the main crop sets. There is reason to believe, from experience, that fruit at

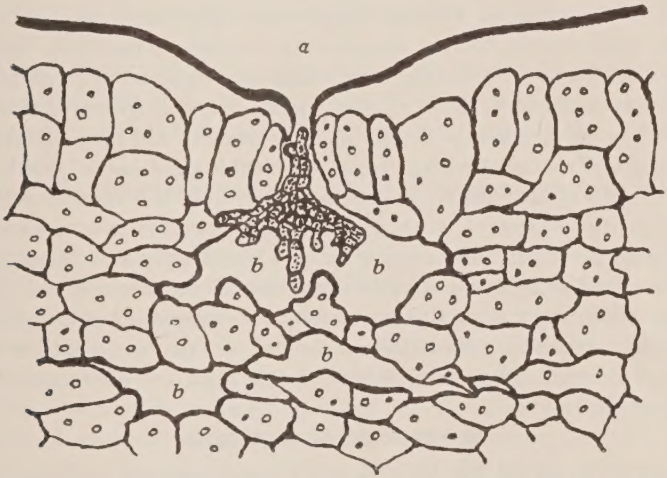

Fig. 3.—A vertical section of the surface of a Fuerte fruit showing a stoma or breathing pore with the surrounding cells more or less broken down (*a*) and the air spaces in the tissue below (*b*, *b*). Mycelium of dothiorella fungus has grown into the open passage of the breathing pore and into the air space below. (Figure drawn somewhat diagrammatically from a photomicrograph kindly made by Dr. Ira Ayer, of Carlsbad.)

its earliest satisfactory stage for harvesting softens more perfectly, and that dothiorella rot develops later and less actively on it than on fruit which has become gray with age and has lost its resilience. Specific evidence is furnished by the difference in behavior of the two lots in the spray experiment of 1934 (page 12).

ATTEMPTS TO PREVENT DOTHIORELLA ROT BY MEANS OTHER THAN BY SPRAYING

Early in these studies, avocado fruits were submitted to various treatments which should destroy spores on the surface of the fruit. None of these was effective. Fruit from dothiorella areas may be wet with strong alcohol and flamed without preventing the rot, and pieces of the skin planted in culture media shortly after treatment will give cultures of the fungus. Treatment with nitrogen trichloride gas (Agene) conducted with the aid of L. J. Klotz, and with and without the vacuum process, failed to prevent the rot, although some applications were severe enough to speckle the fruit. Prevention of this rot is evidently a problem unlike that involved with blue and green-mold rots of citrus fruits.

Control by preventing tipburn and by removing dead twigs presents difficulties concerning the evidence secured, so that we do not have figures to present, although measures of this kind are doubtless of the greatest importance.

EXPERIMENTAL METHODS

We ourselves sorted the fruit at the Calavo Growers packing-house, usually assisted by an experienced member of the Calavo staff. Injuries and blemishes due to physiological breakdown were disregarded. These include cuts, bruises, wounds, scald, speckles, carapace spots, and others. Many doubtful cases were studied further at the laboratory. Decays other than dothiorella rot were comparatively few so that error from misjudging the kinds of decay spots was not important. Many spots of true dothiorella rot appear late and develop so slowly that some of them have done no serious harm until the fruit is spoiled by oversoftness (natural overripening).

Most of the fruits classed as "clean" which were studied further, later developed some dothiorella, but usually this was not of much practical importance. Fruits from the check plots classed as "clean" suffered more on longer keeping than fruits from the sprayed plots. In general, the advantage of the better lots of fruit increased on keeping. This is probably a true result and related with the manner of dothiorella infection.

Experiments with Fuertes from the Citrus Experiment Station at Riverside, where dothiorella is so rare as to be negligible, showed that

some infection might be caused by spores getting on the fruit at harvest, but that the number of infections is so small as to be unimportant in ordinary marketing. In such experiments as those in which young fruits were disinfected and bagged at different stages to find the earliest size at which infection occurs, the results were believed to be approximately correct. However, if all possible error is to be avoided, special methods of handling would need to be employed. The infections produced by inoculating after picking appeared late and developed rather slowly.

The good quality of fruits in the better lots, especially in 1934, and other results difficult to express in figures, indicate that the evidence given by the tables is not unduly favorable to the treatments.

SPRAY EXPERIMENTS FOR THE CONTROL OF DOTHIORELLA ROT, 1931 TO 1934

With the completion of four years of experimental work on the control of dothiorella rot, enough data have now been collected so that certain conclusions of a practical character may be drawn. The experiments were carried on in a commercial manner, in that the orchards used were of an average grade in regard to their condition of thrift and care. The spraying was done by commercial operators. The fruit was picked in a commercial manner and shipped by the usual common carrier to the Calavo house at Los Angeles. Here it was handled in the same way as other shipments except that it was allowed to soften in the packing-house instead of being distributed while firm to the various markets. Determinations were made on the fruit in an early-soft condition.

These experiments were conducted upon trees of the Fuerte variety ranging in age from four to eight years. They were started in 1931, at a time when very little was known about the disease. The first problem was to determine whether or not it could be controlled by the use of a fungicide. For this reason, a maximum number of applications on plots S–1 and D–1 were made the first year (table 1).

The first application was made before the bloom had opened and at two-week intervals, or after each rain or sprinkle until the bloom was over. Thereafter, applications were made monthly until the fruit was matured and picked. These plots received ten applications in all, the first one having been made April 30, 1931.

Plots S–2 and D–2 were treated before the first bloom had opened and at two-week intervals, or after each rain or sprinkle until the bloom was over. Plots S–3 and D–3 were treated once only, that treatment being given after the bloom. Each of these plots was composed of three trees.

All fruit was picked on November 30, 1931, the earliest date at which the fruit had attained a satisfactory oil content.

By the time the 1932 experiment (table 2) was laid out, it was apparent that the insect problem would be of considerable importance

TABLE 1

1931 EXPERIMENT FOR CONTROL OF DOTHIORELLA ROT

Material	Plot No.	Number of treatments	Total number of fruits	Fruits with slight or no dothiorella	Fruits with pronounced or severe dothiorella	Per cent of fruits with dothiorella
Bordeaux 4-4-50	S-1*	10	98	98	0	0
	S-2	4	101	93	8	8
	S-3	1	146	104	42	29
Monohydrated copper sulfate	D-1	10	118	111	7	6
	D-2	4	103	77	26	25
	D-3	1	104	38	66	63
No treatment (basin irrigation)	check	0	154	80	74	50
No treatment (overhead irrigation)	check	0	54	11	43	80
	check	0	40	11	29	70

* In plots lettered "S," the treatment was applied as a spray; in plots lettered "D," as a dust.

TABLE 2

1932 EXPERIMENT FOR CONTROL OF DOTHIORELLA ROT

Material	Plot No.	Number of treatments	Total number of fruits	Fruits with slight or no dothiorella	Fruits with pronounced or severe dothiorella	Per cent of fruits with dothiorella
Bordeaux 4-4-50	S-1*	3	97†	67	30	31
	S-2	3				
	S-3	2	36	26	10	23
	S-4	2	6	4	2	33
	S-5	2	21	18	3	14
	S-6	1	6	4	2	33
Zinc sulfate, 8 lbs. Hydrated lime, 8 lbs. Flotation sulfur, 6 lbs. Casein spreader, 1 lb. Water, 100 gals.	S-7	3	110	70	40	36
	S-8	2	152	84	68	45
	S-9	2	62	54	8	13
	S-10	1	99	85	14	14
	S-11	1	94	76	18	19
Copper sulfate, 8 lbs. Hydrated lime, 8 lbs. Flotation sulfur, 6 lbs. Casein spreader, 1 lb. Water, 100 gals.	S-12	1				
	S-13	1	23‡	23	0	0
	S-14	1				
No treatment	check	0	97	54	43	44

* "S" = Treatment applied as a spray.
† The fruits from plots S-1 and S-2 were combined.
‡ The fruits from plots S-12, S-13, and S-14 were combined.

in avocado-growing districts. Where latania scale[9] was present, fumigation with hydrocyanic acid gas was found necessary. As this material is not compatible with bordeaux or the copper compounds, the necessity for a copper substitute was apparent. For this reason attempts were made to substitute zinc sulfate for copper sulfate, since some investigators reported good results from the use of this material as a fungicide.

In districts where the avocado red mite is a pest, it is necessary to use sulfur in some form for its control. For this reason sulfur was added to several of the formulas.

During this season there was a demand on the part of the growers for a simple method for determining in the field the approximate amount of dothiorella that could be expected to show up in the fruit at the time of softening. It was found that by making an inspection of an orchard and paying careful attention to the following points, a very close estimate could be made: (1) amount of tipburn, (2) number of dead twigs in the trees, (3) amount of dothiorella infection in the tipburned leaves and dead twigs, (4) amount of off-bloom, (5) method of irrigation, (6) insect and other injuries, (7) fungicidal material used, and (8) maturity of the fruit.

From a commercial standpoint, we decided that it would not be practical to make more than three applications of a fungicide in a single season, and for that reason three applications were selected as a maximum number to be used. All fruit was picked as soon as a satisfactory oil content had been attained, which was on November 16, 1932.

Owing to a short crop of Fuertes in 1932, the number of fruits harvested in this experiment was not sufficiently large to be satisfactory for drawing very definite conclusions. However, the 1932 experiment strongly indicated that the addition of sulfur increased the fungicidal value of bordeaux and that zinc sulfate had some promise as a fungicide in the control of dothiorella rot. For this reason, these materials were included in the formulas used in the 1933 experiment (table 3).

The fruit in this experiment was not picked until February 12, 1934, since it had not attained a satisfactory oil content until that date. The 1933 Fuerte crop was again light, and the quantity of fruit examined was rather small.

The lime-sulfur which was used as an insecticide for the control of avocado red spider showed marked fungicidal value. For this reason flotation sulfur applied as a fungicide was tried in the 1934 experiment (table 4).

[9] Latania scale, *Aspidiotus lataniae* Sign.

Since the addition of sulfur to bordeaux had given 100 per cent control of dothiorella rot in 1932 and 1933, it was again used in the 1934 experiment.

In an attempt to find out when infection in the sense of penetration of fruit actually takes place, 100 fruits which had attained a diameter of

TABLE 3

1933† EXPERIMENT FOR CONTROL OF DOTHIORELLA ROT

Material	Plot No.	Number of treatments	Total number of fruits	Fruits with slight or no dothiorella	Fruits with pronounced or severe dothiorella	Per cent of fruits with dothiorella
Zinc sulfate crystals, 8 lbs. Fresh hydrated lime, 8 lbs. Wettable sulfur, 6 lbs. Casein spreader, 1 lb. Water, 100 gals.	S-1*	3	43	32	11	25 6
Zinc sulfate crystals, 16 lbs. Fresh hydrated lime, 8 lbs. Wettable sulfur, 6 lbs. Casein spreader, 1 lb. Water, 100 gals.	S-2	3	110	94	16	14 5
Copper sulfate crystals, 8 lbs. Commercial bordeaux, 16 lbs. Casein spreader, 1 lb. Water, 100 gals.	S-3	3	118	115	3	2.5
Commercial bordeaux, 16 lbs. Wettable sulfur, 6 lbs. Casein spreader, 1 lb. Water, 100 gals.	S-4	3	84	84	0	0.0
Copper sulfate, 8 lbs. Commercial bordeaux, 16 lbs. Wettable sulfur, 6 lbs. Casein spreader, 1 lb. Water, 100 gals.	S-5	3	48	47	1	2 0
Dry lime-sulfur, 6 lbs. Casein spreader, 1 lb. Water. 100 gals.	check	3	292	244	48	16 4

* "S"=Treatment applied as a spray. † Fruit not picked until Feb. 12, 1934.

1½ inches were dipped in 70 per cent alcohol and each covered with a paper bag to prevent further infection. These fruits were bagged on August 2.

The fruits in this experiment were picked in two separate lots, the first lot on November 17, and the second lot 41 days later. The object of this was to determine differences in the amount of infection in early-harvested fruit as compared with that picked at a later date. Fruit from

the check plot of the first picking developed 40 per cent of rot, while that of the second picking gave 70 per cent of rot.

Fumigation experiments were conducted by H. J. Quayle to deter-

TABLE 4

1934 EXPERIMENT FOR CONTROL OF DOTHIORELLA ROT

Material	Plot No.	Number of treatments	Total number of fruits	Fruits with slight or no dothiorella	Fruits with pronounced or severe dothiorella	Per cent of fruits with dothiorella
Zinc sulfate crystals, 16 lbs. Fresh hydrated lime, 8 lbs. Flotation sulfur, 6 lbs. Blood albumin spreader, 6 oz. No. 3 tank-mix oil, ½ gal. Water, 100 gals.	S-1*	3	200	153	47	24.0
Zinc sulfate crystals, 16 lbs. Copper sulfate crystals, 1 lb. Fresh hydrated lime, 8 lbs. Flotation sulfur, 6 lbs. Blood albumin spreader, 6 oz. No. 3 tank-mix oil, ½ gal. Water, 100 gals.	S-2	3	211	179	32	15.0
Zinc sulfate crystals, 32 lbs. Fresh hydrated lime, 16 lbs. Flotation sulfur, 6 lbs. Blood albumin spreader, 6 oz. No. 3 tank-mix oil, ½ gal. Water, 100 gals.	S-3	3	200	190	10	8.0
Commercial bordeaux, 16 lbs. Flotation sulfur, 6 lbs. Blood albumin spreader, 6 oz. No. 3 tank-mix oil, ½ gal. Water, 100 gals.	S-4	3	176	176	1	0.5
Flotation sulfur, 10 lbs. Blood albumin spreader, 6 oz. No. 3 tank-mix oil, ½ gal. Water, 100 gals.	S-5	3	164	157	7	4.0
No treatment	Check	0	410	189	221	54.0
Fruit dipped in alcohol and bagged when fruit had reached 1½ inches in diameter	Bagged fruit	0	72	71	1	1.0

* "S" = Treatment applied as a spray.

mine the compatibility of cyanide with the various materials used in this experiment. The results were as follows:

1. Zinc sulfate sprays were found to be compatible with cyanide.

2. The addition of 1 pound of copper sulfate to each 100 gallons of zinc sulfate spray did not increase its incompatibility markedly.

3. The flotation sulfur was incompatible with cyanide and considerable damage resulted in fumigation over trees sprayed with this material. It is thought that the incompatibility was due to substances other than the sulfur present in this particular spray preparation. It is also felt that the incompatibility would not be of a residual nature as is sometimes the case with the copper compounds.

4. Fumigation over trees sprayed with bordeaux did not result in as serious injury as was expected. However, the experiments were not extensive enough to be conclusive, and serious injury might result from further attempts under different conditions.

SUGGESTED SPRAY PROGRAM FOR DOTHIORELLA ROT

Spray Treatment Without Fumigation.—Where no fumigation is contemplated, there should be two applications with the following formula, the first application to be made when the fruit is about 1½ inches in diameter, the second application to be made about two months later:

Commercial bordeaux (or 4–4–50 homemade bordeaux)	16 pounds
Wettable sulfur	6 pounds
Blood albumin spreader	6 ounces
Water	100 gallons

Spray Treatment with Fumigation.—Where fumigation is contemplated, it should take place as soon as the fruit attains the size of 1½ inches in diameter. Fumigation should be followed at once with an application of wettable sulfur used without the bordeaux; at least one subsequent application of this spray material should be made about 6 to 8 weeks later. The formula for use follows:

Wettable sulfur	6 pounds
Blood albumin spreader	6 ounces
Water	100 gallons

Combination Treatment for Dothiorella Rot and Mottle-Leaf.—Treatment to prevent dothiorella rot may be combined with treatment for mottle-leaf. The first spray should be applied when the fruit has attained a diameter of about 1½ inches, and the second about two months later. If fumigation is practiced, it should precede the first spraying. The formula recommended for this dual purpose follows:

Zinc sulfate crystals	16 pounds
Copper sulfate	1 pound
Fresh hydrated lime	8 pounds
Flotation sulfur	6 pounds
Blood albumin spreader	6 ounces
Water	100 gallons

SUMMARY

Dothiorella rot can be completely controlled by the use of fungicides.

Liquid fungicides are more effective than those applied as dusts.

Dothiorella rot is increased by overhead irrigation.

Copper sulfate is more effective than zinc sulfate in controlling dothiorella rot.

The fungicidal value of copper sulfate when used as bordeaux is greatly increased by the addition of sulfur.

Sulfur alone when applied as a liquid with spreader is a very effective fungicide against dothiorella rot.

The fungicidal value of zinc sulfate is increased by the addition of a small amount of copper sulfate. Copper sulfate when added to zinc sulfate in small amounts apparently does not interfere with fumigation.

For the control of dothiorella rot, zinc sulfate alone, that is, without copper sulfate, must be applied at such strong concentrations as to make it impractical from a commercial standpoint.

It has been indicated that the fruit is not infected until some time after a diameter of 1½ inches has been reached. Therefore, early sprayings are not as important as applications made after the fruit is fairly well developed.

The most effective spray for the control of dothiorella rot is the bordeaux and sulfur mixture prepared according to the formula given on page 14.

The next most effective fungicide is wettable sulfur used alone.

Either of the first two formulas recommended on page 14 also give satisfactory control of the avocado red spider.

If the fruit is picked as soon as possible after it has attained a satisfactory oil content, infection will be greatly reduced, particularly on unsprayed trees.

Spray recommendations for the control of dothiorella rot must be based upon the combination of insects and diseases for which control measures are necessary.

ACKNOWLEDGMENTS

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